FINAL REPORT
Large Scale Distributed Computation for Human Agent Team Coordination in Dynamic Environments
Organization: Carnegie Mellon University and University of Pittsburgh
PIs: Katia Sycara (CMU) (PI)
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Cumulative list of people involved in the Effort
- Katia Sycara (PI)
- Paul Scerri (faculty, CMU)
- Michael Lewis (faculty, U of Pittsburgh)
- Sean Owens (research staff, CMU)
- Robin Glinton (research staff, CMU)
- Joseph Giampapa (research staff, CMU)
- Bin Yu (postdoc, CMU)
- Prasanna Velagapudi (PhD student, CMU)
- Steve Chien (PhD student U of Pittsburgh)
- Zeng Ma (PhD student, U of Pittsburgh)
- Jijun Wang (PhD student, U of Pittsburgh; PhD granted 2007)
- Huadong Wang (PhD student, U of Pittsburgh)

Information must be sorted out and fused not only to allow commanders to make situation assessments, but also to support the generation of hypotheses about enemy force disposition and enemy intent. While incredible progress has been made on information fusion in recent years, the sensing capabilities available have advanced even faster. Moreover, the sheer number of platforms available to commanders has dramatically increased. Perhaps more importantly, the context in which information is being fused, shared and used is changing dramatically from carefully defined hierarchical information pathways to a dynamic, open net-centric information sharing and planning. In this work, we focused on issues related to this new reality.

Our research has focused on the problems of developing integrated techniques for fusion levels 2 and 4. Our work can be roughly divided into modeling, understanding and improving sensor fusion in a net-centric environment (level 2) and modeling, understanding and improving humans ability to use multiple mobile sensor platforms to collect information required for planning and acting.

In this report we present a very brief summary of our work in each of these areas accompanied by reprints of papers presenting the research in detail.

Level 2: techniques for integrating diverse sensors and recognizing aggregated forces

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One of the emerging problems in Network Centric Warfare is where to fuse data and make decisions in a large distributed system. We have been looking developing and analyzing models of how information might be shared and fused in very large cooperative groups [1, 2, 3, 4, 6]. A key finding in that work is that the details of the network structure and how conclusions are shared have a very large impact on overall performance. In [1], we present a completely local algorithm that helps teams reach more accurate conclusions more regularly. We added simple models of human cognitive processes to these models and looked at how human characteristics might influence large-scale fusion [5]. Finally, we began to look at lightweight algorithms that could be used to effectively share information in large networks, while respecting bandwidth constraints [7, 8].

Level 4: methods for tasking assets or assisting humans to acquire new information

The process of acquiring information for fusion or acting on it after it is acquired requires tight coordination among sensor platforms and other assets. As the size of such systems increases it becomes necessary to automate this coordination. Conventional approaches to automated coordination do not scale well above 10-20 entities and become very difficult for humans to understand or control at even smaller numbers. Much of our work under this contract has focused on how humans can effectively manage an increased number of mobile sensor platforms. One thread of research was related to high-level interface concepts for making sensor data available to humans, e.g., by abstracting away from individual sensors [10] or changing time constraints on how humans must deal with data [11, 12, 15]. Another research thread looked at how humans and robots were organized to manage the data volume. One paper looked at how human organizations could be organized better [9], another looked at humans as a sensor to be leveraged by a robot team [13], others looked at how teams of humans would manage teams of robots [23, 24]. A series of important experiments with real human subjects looked in depth at how humans can deal with a larger number of robot platforms [14, 15, 16, 17, 18, 19, 20, 21, 25]. These experiments resulted in new knowledge about limits on and factors effecting humans. Finally, some work looked at better autonomous algorithms for supporting information collection [27, 28].

Simulation Tools and Environments

The USARSim simulation, developed as a part of this research, has become an important tool for the research community at large to look at issues of human control of multiple robots [22]. In collaboration with NIST, we have continued to developed the simulator. Urban Search and Rescue Simulator (USARSim) is now the platform for the search and rescue competition at RoboCup, a competition that attracts 10s of teams each year. USARSim now uses a newer version of the Unreal Tournament (UT) engine, UT3, and has been made distributed. This upgrade allows better physics, better graphics and many robots in the same environment. Our work with human control of wide area search munitions through cooperative control software based on our work was used by Wright Patterson AFB for a detailed examination of humans ability to control up to 16

munitions, a study which definitely showed the value of autonomous coordination.

Scientific Accomplishments

The scientific accomplishments of this work can be roughly divided into two areas: large-scale information sharing and fusion and human interaction with mobile sensors.

Important scientific advances were made on how information sharing and fusion might work in future net-centric organizations. Extensive use was made of multi-agent simulation to understand key dynamic processes and emergent effects. The dynamics of the information sharing were found to be dominated by cascades of changes in belief due to a single additional sensor reading. A key finding was that large organizations may reach the wrong conclusion more than the quality of the incoming sensor information would suggest. An algorithm to improve the ability of the organization to reach correct conclusions was developed. Mathematical models of the interesting phenomena were developed, borrowing techniques from physics. These models exposed additional phenomena that simulation could not. Other fundamental research on information propagation in networks showed that often random information propagation was as much as half as good for the team as a theoretical upper bound on information sharing performance.

Previous work had shown that a human can effectively manage up to between 2 and 12 autonomous assets before becoming overloaded. However, relatively little work had looked at what techniques might increase that limit. Important scientific advances were made to understand the reasons for the limit and how it might be raised. One important finding was that human cognitive resources were heavily consumed with path planning and that by automating that path-planning a single human could control many more assets. A much deeper understanding of how much time humans spend monitoring robot sensor feeds resulted from large sets of experiments. This understanding was leveraged into new interface concepts for which preliminary experiments were performed. One of these concepts, a *call center*, makes dramatically better use of human time by having the robots autonomously decide when they need human input.

PUBLICATIONS
Level 2: techniques for integrating diverse sensors and recognizing aggregated forces

[1]   Robin Glinton, Praveen Paruchuri, Paul Scerri, Katia Sycara "Self-Organized Criticality of Belief Propagation in Large Heterogeneous Teams", In Dynamics of Information Systems: Theory and Applications, Springer 2010

[2]   Robin T. Glinton, Paul Scerri, Katia Sycara "Towards the Understanding of Information Dynamics in Large Scale Networked Systems", In Proceedings of FUSION 2009.

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Level 4: methods for tasking assets or assisting humans to acquire new information

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[15]   Sean Owens, Katia Sycara, Paul Scerri "Using Immersive 3D Terrain Models For Fusion Of UAV Surveillance Imagery" In Proceedings of AIAA 2009.

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[17]   Velagapudi, P., Wang, H., Scerri, P., Lewis, M. & Katia Sycara (2009). Scaling effects for streaming video vs. static panorama in multirobot search, 2009 International Conference on Intelligent Robots and Systems (IROS 09), IEEE

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Carnegie Mellon University
Robotics Institute
5000 Forbes Av.
Pittsburgh, PA 15213

University of Pittsburgh
School of Information Science
135 N. Bellefield Av.
Pittsburgh, PA. 15260

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Dr. David Luginbuhl
AFOSR
875 N. Randolph Str.
Suite 325
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14. ABSTRACT
Recent research and technological advances are harbingers of scenarios where large scale crisis response in civilian and military domains can be facilitated by autonomous sensing and effecting entities. To make this a reality scientific research shortfalls must be addressed, notably the challenge of scalability. Current multi-agent coordination techniques do not scale to large numbers of agents. Therefore, the goals of this research are (1) to discover ways in which large numbers of autonomously computing entities (including software agents and physical robots) must be coordinated in effective ways, and (2) ways for human operators to supervise and control robotic agents. In particular, we want to develop techniques that allow large scale coordination in the execution of complex missions in uncertain and dynamically changing environments. To achieve this goal a variety of key research issues will be addressed. Specifically, we will develop (a) tractable automated coordination algorithms, (b) efficient techniques for fusing information, and (c) techniques for allowing effective and flexible control of agent groups by small numbers of human operators.

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